

A Novel Approach of Sensitive Infrared Signal Detection for Space Applications

Completed Technology Project (2013 - 2014)



Project Introduction

Develop an innovative frequency up-conversion device that will efficiently convert the infrared signals into visible/near-infrared signals to enable detection of infrared signals with high sensitivity, high dynamic range, fast response, and low noise background.

We propose an innovative approach to overcome the infrared signal detection difficulties. In this investigation, a Periodical Poled MgO Lithium Niobate (PPMgOLN) based frequency up-conversion devices will be developed to efficiently convert the infrared signals into visible/near-infrared signals which can be sensitively detected by well-developed superior silicon avalanche photodiodes (Si-APD). This innovative device will allow detect infrared signals with high sensitivity, high dynamic range, fast response, and low noise background.

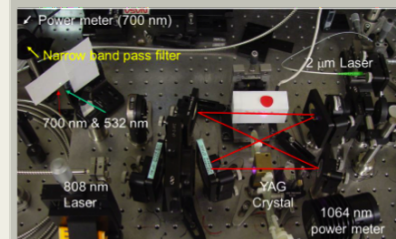
The principle of up-conversion device is based on non-linear interaction between two optical beams. When a strong pump beam and a weak probe beam interact in a suitable nonlinear crystal, a signal at third frequency is generated under the condition of energy and momentum conservation. For example, interaction between a pump beam at $1.06\mu\text{m}$ and weak infrared $2.05\mu\text{m}$ beam in the PPMgOLN crystal can generate photons at $0.7\mu\text{m}$ wavelength. The number of probe photons is much smaller than that pump photons because the probe beam is usually very weak. Only a small portion of pump photons have the chance to mix with probe photons to generate photons at sum frequency of the pump and probe beam. Therefore, the circulating power in the crystal is constant because of the negligible pump depletion. In theory, every infrared probe photons can be converted into visible/near infrared photons

An intra-cavity pumped up-conversion device is designed to demonstrate the frequency up conversion capability. One periodically poled PPMgOLN is used in this study. A CW 808 nm diode laser is used to pump a Nd:YAG rod inside the cavity to generate the 1064 nm pump beam. The leakage of 1064 nm light is used to monitor the circulating intra-cavity pump power. A two-micron DFB laser was also aligned through the PPMgOLN to simulate the weak probe beam. CaF₂ dispersion prisms and laser line filters were used to separate the generated 700 nm photons from the photons at other wavelengths for accurate visible signal measurement.

The up-converted photons can be measured with Silicon Single Photon Avalanche Photodiode detector to take advantages of its high quantum efficiency and low dark current. Thus, extremely weak infrared signal can be measured with unprecedented sensitivity and accuracy.

Anticipated Benefits

The near-infrared and mid-infrared wavelengths offer intrinsic advantages in remote sensing and lidar operations. The overtone and fundamental



Project Image A Novel Approach of Sensitive Infrared Signal Detection for Space Applications

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rovibrational spectrum of gas molecules are in this region, offering the opportunity to optically measure the concentration of these trace gases. The frequency up conversion combined with optical detection for molecular species in the NIR and MIR directly addresses the infrared sensor technology that is far better than what is currently available from custom-built Indium Gallium Arsenide (InGaAs) or Germanium (Ge) Geiger-mode APDs. In Earth science, infrared is key in the detection of trace gasses like carbon dioxide and methane. These two gases are the most important greenhouse gases for climate change and global warming studies.

Sensitive infrared signal/image detection shall have variety of science applications in astronomy and passive and active remote sensing where weak NIR and MIR signal detection are needed. This technique provides the infrared photon detectability to single molecule detection level. An example of immediate application is to integrate this device to DIAL lidar to detect atmospheric carbon dioxide concentration with high sensitivity.

Sensitive detection of infrared signal is critical needed technology in commercial and defense fields. This technology can improve the signal detection in chemical and biological warfare agents for DoD and Homeland Security. The capability to detect single photon in infrared wavelength region is unprecedented.

This technology can be used in enhancing the capability of high-sensitivity classical optical communication. Using a commercial Silicon (Si) Geiger-mode avalanche photodiode (APD) to perform photon counting on the upconverter's output of telecommunication wavelength photons at 1.55 μ m would afford sensitive single-photon counting capability in the fiber-optic and atmospheric transmission bands. The low-loss transmission windows in the short (S), conventional (C), and long (L) wavelength telecommunication bands are particularly well suited for long-range communication with geo-synchronous satellites and for high-sensitivity interplanetary optical data transmission.

Frequency up conversion can also enhance and enable several quantum information technologies. Upconversion be used to prepare complex quantum states by partially upconverting a photon into an arbitrary superposition of two frequencies. This, in addition to polarization, angular momentum, and time-bin, provides another degree of freedom for transmitting quantum information.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Langley Research Center (LaRC)

Responsible Program:

Center Independent Research & Development: LaRC IRAD

Project Management

Program Manager:

Julie A Williams-byrd

Project Manager:

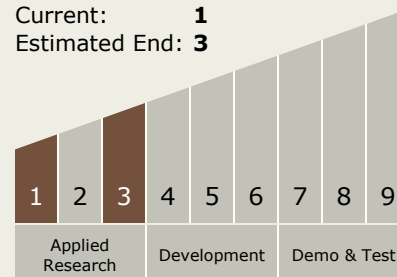
Jirong Yu

Principal Investigator:

Jirong Yu

Technology Maturity (TRL)

Start: **1**
 Current: **1**
 Estimated End: **3**

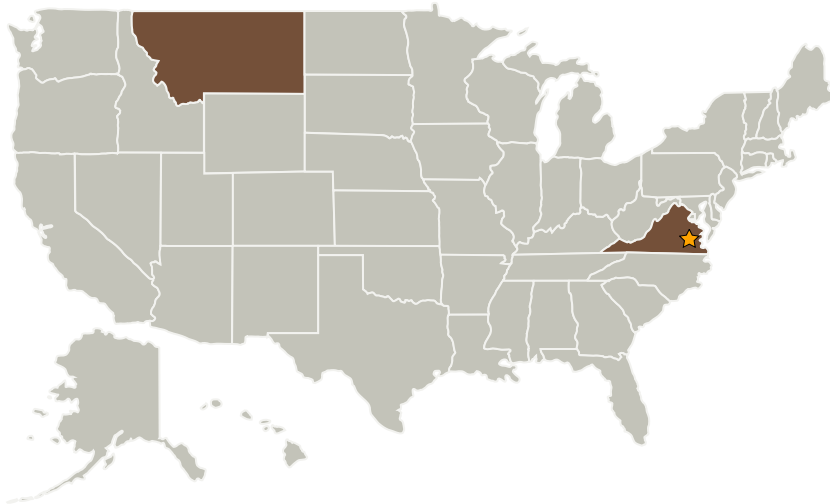


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Primary U.S. Work Locations and Key Partners



Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
 - └ TX12.2 Structures
 - └ TX12.2.4 Tests, Tools and Methods

Organizations Performing Work	Role	Type	Location
★ Langley Research Center (LaRC)	Lead Organization	NASA Center	Hampton, Virginia

Co-Funding Partners	Type	Location
Montana State University - Bozeman	Academia	Bozeman, Montana

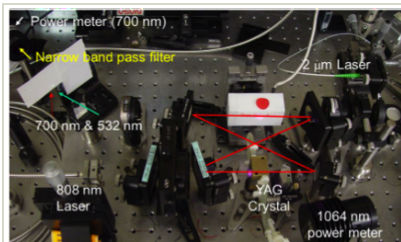
Primary U.S. Work Locations	
Montana	Virginia

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Images



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(<https://techport.nasa.gov/image/2277>)